

# BASELINE MAPPING OF DISCONTINUITIES THROUGH NONDESTRUCTIVE TESTING

by

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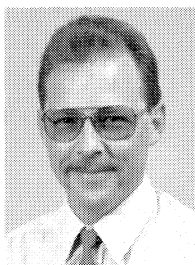
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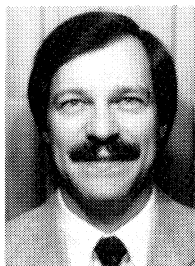
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## ABSTRACT

Manufacturers in the compressor industry have experienced an increasing interest by their customers to be able to compare the as manufactured condition of critical components to their subsequent condition over time in service. Through the use of nondestructive testing, combined with baseline mapping of benchmark indications, this can be accomplished on specific components under controlled conditions. The purpose of this presentation is to discuss the following areas under which baseline mapping can be successfully accomplished.

- Nondestructive Testing (NDT)
- Liquid Penetrant
- Magnetic Particle
- Ultrasonic
- Radiography
- Visual
- Baseline Mapping
- Common Mapping Methods
- Types of Maps
- Mapping Variables
- Mapping Requirements
- Benefits Vs Cost

## NONDESTRUCTIVE TESTING

Nondestructive testing is a term used to describe a variety of methods employed to determine the physical soundness of an item without damaging or destroying the item being tested. The American Society for Nondestructive Testing, Inc. (ASNT) publishes qualification and certification guidelines for nine nondestructive testing methods.

- Liquid Penetrant Testing (PT)
- Magnetic Particle Testing (MT)
- Ultrasonic Testing (UT)
- Radiographic Testing (RT)

- Visual Testing (VT)
- Electromagnetic Testing (ET)
- Neutron Radiographic Testing (NRT)
- Leak Testing (LT)
- Acoustic Emission Testing (AET)

Of these nine methods, the five most commonly used methods in Turbomachinery Manufacturing are:

- Liquid Penetrant (PT)
- Magnetic Particle (MT)
- Ultrasonic (UT)
- Radiography (RT)
- Visual (VT)

A very brief description of the five most commonly used NDT methods and a listing of their advantages and disadvantages follows.

### LIQUID PENETRANT

Liquid penetrant testing is a nondestructive means of locating surface discontinuities based on capillary action. In liquid penetrant testing, the liquid is applied to the surface of the item. Time is allowed for the penetrant to enter surface discontinuities. After sufficient time, the surface of the part is cleaned. A developer is applied to help draw the penetrant out and to make the indication more visible by providing a contrasting background. The contrasting background is created because the penetrant contains either a colored dye seen easily in white light, or a fluorescent dye visible under ultraviolet light (commonly known as black light). Liquid penetrant testing is limited by its ability to detect discontinuities that are *open to the surface*. It is also limited in detecting discontinuities in porous material. Liquid penetrant testing can be used on impellers made from nonmagnetic materials. Some of the advantages and disadvantages of liquid penetrant testing are:

#### *Advantages*

- Best method for finding indications open to the surface in nonferrous material
- Can be used on ferrous and nonferrous material
- Good for volume testing small parts
- Good to find a wide range of discontinuities
- Good for spot checking
- Some methods are portable

#### *Disadvantages*

- Can only find indications open to the surface.
- Extensive precleaning is required
- Not reliable on porous surfaces.
- Florescent penetrant requires a darkened area.
- Materials are flammable.
- Removal of excess penetrant is time consuming.
- If indications are obstructed by foreign matter, they will be difficult or impossible to find.
- Skilled personnel are required to evaluate indications.

### MAGNETIC PARTICLE TESTING

Some materials are repelled by a magnet. These materials are called diamagnetic. Some materials are attracted by a magnet.

These materials are call paramagnetic. A subdivision of paramagnetic materials is a group of materials known as ferromagnetic.

Ferromagnetic materials are those materials strongly attracted to a magnetic field.

Magnetic particle testing is a nondestructive testing method used for locating discontinuities at or near the surface of ferromagnetic materials.

Magnetic particle testing depends upon establishing a magnetic field within an item. Discontinuities that lie approximately transverse to the direction of the magnetic field will cause a magnetic leakage field at and above the surface of the item. This leakage field is then detected by applying small ferromagnetic particles over the surface. Some of these particles will be held by the leakage field. These magnetically held particles will indicate the location, shape, and size of the discontinuity.

Magnetic particle testing can be used on impellers made from magnetic materials. Some of the advantages and disadvantages of magnetic particle testing are:

#### *Advantages*

- It is the best method for detecting surface cracks on ferromagnetic materials.
- It will detect indications filled with foreign matter.
- Extensive precleaning is usually not necessary.
- Works through thin nonmagnetic coatings such as paint and plating.
- It lends itself to automation.
- Equipment can withstand shop environment.

#### *Disadvantages*

- It will only work on ferromagnetic materials.
- Not an expedient method for doing large volumes of small parts.
- Odd shaped parts sometimes distort the magnetic field.
- Magnetic field must be applied in a direction that will be transverse to the indication.
- Demagnetization is often necessary.
- Care must be taken to avoid arc strikes.
- Skilled personnel are required to evaluate indications.

### ULTRASONIC TESTING

Ultrasonic testing is a nondestructive testing method for inspecting materials by injecting high frequency sound waves into or through materials. The high frequency sound waves are used to detect surface and subsurface indications.

An ultrasonic transducer is used to transmit and receive these sound waves. The transducer converts the mechanical energy into electrical energy.

The transducer is connected to an electronic device that:

- Generates the electronic signal.
- Receives the electronic signal.
- Displays the electronic signal so an evaluation of that signal can be made.

In sound material, the energy reflects off the back surface and returns to the transducer. In material with a discontinuity, some of the original energy is reflected by the discontinuity and returns to the transducer. The ultrasonic unit uses this difference in the amount of sound energy returned and the elapsed time to locate the

discontinuity. This is a very simplified description of the basic principal of ultrasonic testing.

There are many variables that affect ultrasonic testing. Therefore, it cannot be stressed enough that it is essential for the UT operator to have the training and experience necessary to perform the required ultrasonic tests.

Ultrasonic testing can be used on shaft forgings. Some of the advantages and disadvantages of ultrasonic testing are:

#### Advantages

- High sensitivity for detection of small discontinuities.
- Greater accuracy in determining the location of discontinuities.
- Penetrating power allows examination of thick items.
- Electronic operation allows fast response, automated testing and easily adapted for printing out permanent records.
- Allows volumetric scanning.
- Contact testing allows testing of large items and uses a minimum of instrumentation.
- Portability

#### Disadvantages

- Extensive training and experience is required for the operators.
- Extensive technical knowledge is required for developing UT procedures.
- Unfavorable geometry, parts that are rough, irregular in shape, small or thin are very difficult to inspect.
- Nonhomogeneous material or undesirable internal structure like grain size or inclusions and defect orientation may be to such extent that the item cannot be tested ultrasonically.
- Large number of accessories required for immersion testing which also limits the size of the article that can be immersion tested.
- Reference standards are needed for sizing defect and for calibrating equipment.

## RADIOGRAPHIC TESTING

Radiography is a nondestructive testing method that uses electromagnetic energy such as X-rays or gamma rays to examine material for internal quality.

Radiography is based on the differential absorption of the penetrating radiation by the object being tested.

Differences in thickness, and material composition such as density or absorption characteristics cause different portions of a test piece to absorb different amounts of radiation. The radiation that passes through the test piece can be recorded on film, photo-sensitive paper, viewed on a screen or monitored by various electronic equipment. The basic process is shown in Figure 1.

More radiation passes through the areas that are thin or that contain voids. This unabsorbed radiation exposes the emulsions in the film. When developed, the corresponding areas of the film are darker.

Radiography can detect indications that create a thickness variation as compared to its surrounding area. The thickness variation caused by indications that are oriented parallel to the radiation beam and, in general, have a two percent or more absorption difference can be detected.

As in UT, one of the most important factors is to have trained experienced personnel perform the work.

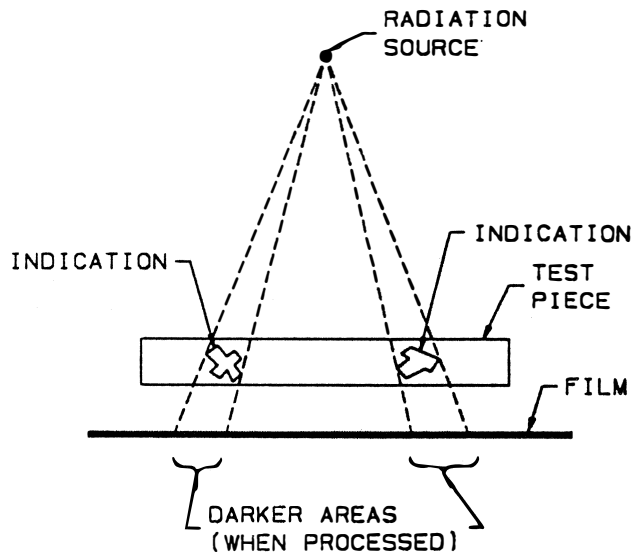


Figure 1. Typical Radiographic Inspection Showing Radiation Source, Test Piece, and Film Placement. Also shown are the emission and spread of radiation, penetration of the test material, and projection of images onto the film.

Radiography can be used on butt welds on fabricated casings. Some of the advantages and disadvantages of radiography are:

#### Advantages

- Can be used on most materials including ferrous, nonferrous, nonmetallic, and composites.
- Can detect internal discontinuities.
- When required, can provide a permanent record.
- Can reveal assembly errors.

#### Disadvantages

- Impractical to use on parts with complex geometry—when source, part, and film cannot be properly orientated, RT is of no use.
- Both sides must be accessible.
- Requires large capital outlay if purchasing equipment.
- Expensive if testing thick items that require high energy equipment.
- Mandatory safety regulation compliance is costly and time consuming.
- Improper use or disregard of safety regulations leading to overexposure can cause blood cell and skin damage. Large overexposure can cause severe disability and even death.
- Certain flaws are difficult to detect—cracks transverse to the radiation beam, small inclusions, and microporosity. Laminations are nearly impossible to detect due to their unfavorable orientation.
- Extensive training and experience are required for operators.

## VISUAL TESTING

Unaided visual inspection has been and still is an important nondestructive testing method. Visual testing is the careful examination of a surface by experienced personnel knowledgeable in the product they are inspecting. Visual testing is performed under

proper lighting conditions in order to identify surface imperfections. Keep in mind that imperfections are not necessarily defects. Some specifications require that visual testing be aided by a five times or ten times magnifying glass. However, most visual testing is unaided. Personnel certified to perform nondestructive testing are required to pass an annual eye examination to assure that their normal or corrected vision meets minimum requirements.

Visual testing is also a convenient preliminary test. Many NDT specifications require a visual inspection before performing the required NDT.

Visual testing is usually required before most fluorescent type NDT inspections since they are performed in a darkened area. Visual testing can be used on diaphragms. Some of the advantages and disadvantages of visual testing are:

#### *Advantages*

- Inexpensive
- No special equipment
- Can be used to detect surface contamination like slag or rust.
- Adaptable for use with borescopes, fiber optics and cameras.

#### *Disadvantages*

- Slow and tedious.
- Requires complete attention by the inspector.
- Human factor is involved.

### **BASELINE MAPPING**

Baseline mapping can be defined as the permanent record of indications resulting from the nondestructive testing of an item. This record can then be used as a future reference for subsequent NDT of the same item. Baseline mapping can be thought of as creating a benchmark, or starting point, that can be referred to at a later date. The baseline map would be used to compare the as manufactured condition of an item to the present condition of the item.

The comparison will then show what has happened to the original indications after the item has been subjected to service conditions.

The evaluation of the results of the comparison can help concerning the disposition and serviceability of that item.

The most common NDT methods used for baseline mapping are:

- Visual Testing (VT)
- Liquid Penetrant Testing (PT)
- Magnetic Particle Testing (MT)

The advantages and disadvantages of each method were discussed earlier. Their use for baseline mapping is usually:

- VT on finished parts
- PT on finished parts both magnetic and nonmagnetic materials
- MT on semifinished and finished parts made of magnetic materials

### **BASELINE MAPPING—APPLICABLE COMPONENTS**

Baseline Mapping is used in conjunction with inservice inspections of critical parts during a routine shutdown.

As such, baseline mapping is used on the following critical components:

- Casings
- Rotor assemblies—including impellers, turbine blades, and any exposed areas on shafts.

- Diaphragms

Maps will provide information on relevant inherent and processing discontinuities. Rotor assembly maps furnish information on all accessible areas of items containing relevant indications that make up the rotor assembly.

Certain items like impellers may be mapped individually before they are assembled on the rotor, but keep in mind that mapping the individual component may provide information that is different than mapping the assembled component. Why it may provide different information has to do with the variables of mapping, which will be discussed later.

### **COMMON MAPPING METHODS**

To be successful, the mapping method should be carefully selected based on the amount of detail required and subjectivity allowed. In addition, basic requirements must be met to ensure that the resultant baseline maps are of subsequent use and value. To ensure the usefulness of a baseline map traceability of the component to the map is critical, without traceability the map will be of no use or value. In addition, an inspection plan should be developed and include as a minimum, the inspection procedure, mapping method with instructions, and standardized documentation and records. The inspection plan should be reviewed, and approved by the manufacturer and customer prior to implementation. This will assure consistent inspection, mapping method, and documentation.

A major concern is the accuracy of interpreting indications and determining their relevancy (relevant vs nonrelevant indications), only relevant indications should be recorded and mapped (Table 1). Records/maps require accurate classification, dimensioning, and location/orientation of relevant indications to assure the map can be used as a subsequent engineering tool (Figure 2). In order to assure accurate interpretation of maps, the part and map should be identified with a starting point.

*Table 1. Interpretation of Common Indications Identified through Nondestructive Testing.*

#### *Interpretation Through Visual, Magnetic Particle and Liquid Penetrant Testing*

##### *False Indications*

Cleanliness  
Surface roughness  
Material geometry

##### *Nonrelevant Indications*

Material geometry  
Material permeability  
Over magnetization

##### *Relevant Indications*

<i>Fabrication</i>	<i>Forging</i>	<i>Plate</i>
Cracks	Cracks	Cracks
Lack Fusion	Laps	Laminations
Undercut	Bursts	Inclusions
Porosity	Seams	
Inclusions	Inclusions	

*Discontinuities* - Relevant indication *meet criteria* - component considered candidate for mapping.

*Defects* - Relevant indications *exceed criteria* - indications rejected.

<b>Nondestructive Testing Baseline Mapping Record</b>		
Part Number: _____	Part Name: _____	Insp Date: _____
Serial Number: _____	Contract Number: _____	
Inspection Method: _____	Inspection Agency: _____	
Inspection Specification: _____		
NDT Inspector/Level: _____		
<u>Sketch:</u>		
<u>Area Identifiers:</u>		
<u>Relevant Indications:</u>		
1. _____	6. _____	
2. _____	7. _____	
3. _____	8. _____	
4. _____	9. _____	
5. _____	10. _____	
(Continue on reverse side when required)		

- What parts require mapping?
  - As stated before this is usually the casing, diaphragm and rotor.
- What NDT method will be used?
  - PT, MT, or VT?
- What NDT technique will be used for each method?
  - PT—Visible dye or fluorescent?
  - Solvent removable or water washable?
  - MT—Prods, coils, clamps, or yoke?
  - Visible or fluorescent?
  - Dry powder or wet particles?
  - Is the NDT reasonable to perform based on manufacturers capability, limitations of the particular NDT method, or size of the part?
    - A large compressor casing might be difficult to inspect using wet fluorescent MT because the casing must be tested and inspected in a dark area.
- What type and size of relevant indications will be mapped?

- The manufacturer will have either a procedure or recommended guidelines that address this.

After the above requirements are established and agreed upon, they become part of the contract and, as stated previously, it is essential that these requirements be duplicated during subsequent NDT by the owner.

If the customer and manufacturer work together, the above requirements can be established and meaningful results obtained. The following is a summary of baseline mapping requirements from customer request to implementation.

#### **BASELINE MAPPING REQUIREMENTS**

- Customer request for baseline mapping
- Review current inspection technique to determine repeatability during inservice inspection
- Approve or modify current technique as required
- Select mapping method
- Generate inspection plan including
  - Inspection technique
  - Mapping method and instructions
  - Standardized documentation
- Review and approve plan

- Enter approved plan into the contract

- Implement baseline mapping in accordance with approved inspection plan

Since mapping is not routinely done and since it is very time consuming, it follows that mapping is an added expense that shall be agreed upon during contract negotiations.

#### **BENEFITS VS COST**

The use of baseline mapping can be of great benefit as an engineering tool. However, if not properly planned and implemented, it can be costly, generate conflict, and result in information that is not accurate or of use. Baseline mapping should be considered only for critical and highly stressed components or areas of components. Components with complicated geometry require maps with greater detail resulting in increased time and cost.

One of the benefits of baseline mapping is the documentation of the benchmark condition of an as manufactured component which can subsequently be compared to the components condition after time in service. Another benefit is in providing documentation to assist in determination of indication propagation rates that can be used to develop product confidence levels and possibly extend product life. Maps can also be useful in establishing in service maintenance and inspection schedules.